Effects of Fuel - Air Ratio on the Flame Propagation for S.I. Engines

تاثير نسبة الوقود – الهواء على تقدم اللهب لمحرك احتراق داخلي يعمل بالشرارة

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الملخص:

نتيجة التوسع الهائل في استخدام وسائل النقل المختلفة، اتجهت البحوث الحالية الى الاهتمام المتزايد بتصميم و تطوير محركات لاحتراق الداخلي لتحقيق امثل سرعة لعمليات الاحتراق و تقدم اللهب خلال خليط الهواء و الوقود و الحصول على اعلى كفاءة و افضل اداء للمحركات و لضمان حرق الوقود الداخل الى حجرة الاحتراق للاستفادة من طاقة جميع الوقود الداخل الى الاسطوانة.

هذا العمل يتضمن دراسة معادلات التفاعل لعملية الاحتراق لثلاث حالات عندما يكون الخليط ضعيف، متعادل كيميائياً و غني و دراسة نواتج الاحتراق و تاثيرها الجانبي على البيئة.

Abstract:

As a result of the rapid development in the various transport means, a great concern was shown in the design and development of spark-ignition engines to achieve the best efficiency and performance and to guarantee a full combustion of the fuel inside the combustion chamber to avail all the energy of the fuel entering the cylinder.

This work involves the study of the reaction equations of the combustion for stochiometric and rich cases, and the study of combustion products and their effects on the environment.

Introduction

Flames can be divided into stationary and propagating flames. The propagation of the flame front happen rapidly through the mixture while stationary flame front is more or less stationary in space. Stationary flames are also categorized into three classes according to the nature of premixing of the reactants. In the first, the fuel oxidant are introduced separately into combustion chamber and the rate of burning is mainly depends on the rates of diffusion of the fuel and oxidant are kept separate, many industrial practices use the diffusion flames. The second general type of stationary flames is that in which the fuel and oxidant are premixed before introduced into combustion and is known as premixed flame. In the third, the fuel and oxidant be partially premixedwith additional air supplied through a separated section to complete combustion. This type known as double flame (inner premixed and outer diffusion flame). In spark ignition engines the type is premixed flame with spherical coordinate.

When a spark plug is fired, the high voltage, high energy discharge ignites the air-fuel mixture between and near the electrodes. This creates a spherical flame front that propagates outward into the combustion chamber. In the initial stage, the flame front moves very slowly because of its small original size. It does generate enough energy to quickly heat transfered the surrounding mixture and thus propagates very slowly. If the temperature of fuel - air mixture is not high (less than SIT,spark ignition tempreture), the flame will be distinguished.

It is desired to have a rich air – fuel mixture around the electrodes of the spark plug during ignition. A rich mixture ignites more rapidly, has a faster flame fronts speed, and gives a better start to the overall combustion process.

Understanding of the mechanism of flame initiation and flame front propagation is considered to be important. More important is the effect of the operating condition on flame in ICE, towards which the research is directed.

Combustion reactions:

Spark ignition engines obtain their energy from the combustion of hydrocarbon fuel with air, which converts chemical energy of the fuel to interval energy in the gases within the engine. There are many types of different hydrocarbon fuel components, which consists mainly of hydrogen and carbon. The maximum amount of chemical energy that can be released (heat) from the fuel is when it reacts (combusts) with a stochiometric amount of oxygen. Stochiometric oxygen is just, enough to convert all carbon in the fuel to CO_2 and all hydrogen to H_2O.

At the end of compression stroke the cylinder contains the mixture of air and fuel mixed with each other through carburetion process in carburetor. Air is used as the source of oxygen to react with fuel.

For actual combustion in a S.I. engines, the equivalence ratio is a measure of fuel-air mixture relative to stochiometric conditions, which is defined as [1,2]:-

$$\Phi = (FA)_{act} / (FA)_{stoich} = (AF)_{stoich} / (AF)_{act} \qquad (1)$$

where,

$FA = m_f / m_a$: fuel-air ratio

$AF = m_a / m_f$: air-fuel ratio

m_a : mass of air

m_f : mass of fuel

when,

$\Phi < 1$ running lean, oxygen in exhaust

$\Phi > 1$ running rich, CO and fuel in exhaust

$\Phi = 1$ stochiometric, maximum energy released from fuel

spark ignition engines operate normally with an equivalence ratio in the range 0.9 to 1.2 depending on the type of operation.

Mixture preparation and fuel-air ratio

The composition of the working fluid (fuel-air) mixture for spark ignition engines after compression stroke consists of air, fuel and residual gasses. In the analysis of working fluid at the trapped conditions, three cases are possible:-

A-weak mixture (Φ < 1.0)

$$C_n H_m + xO_2 + 3.76\, xN_2 \rightarrow a_1 CO_2 + a_2 H_2O + a_3 N_2 + a_4 O_2 \quad (2)$$

Where,

n : number of carbon atoms

m : number of hydrogen atoms

x : number of moles of oxygen

a_1 : number of moles of CO_2

a_2 : number f moles of H_2O

a_3 : number of moles N_2

a_4 : number of moles of O_2

for the hydrocarbon fuel employed in S.I. engines, the number of hydrogen atoms can be obtained from the following equations:-

$m = 2n + 2$ (3)

to obtain the number of moles ($a_1 – a_4$) a mass balance for carbon, hydrogen, oxygen and nitrogen is performed:

For Carbon $a_1 = n$ (4)

For Hydrogen $a_2 = m/2$ (5)

For Nitrogen $a_3 = 3.76\, x$ (6)

For Oxygen $a_4 + a_2 / 2 + a1 = x$

$a_4 = x – n – m / 4$ (7)

B-stochiometric mixture
(Φ = 1):

$C_n\ H_m + xO_2 + 3.76\ xN_2 \rightarrow a_1\ CO_2 + a_2\ H_2O + a_3\ N_2$ (8)

Mole balance of carbon, hydrogen, nitrogen gives:

For Carbon $a_1 = n$ (9)

For Hydrogen $a_2 = m / 2$ (10)

For Nitrogen $a_3 = 3.76\ x$ (11)

C-Rich mixture (Φ > 1):

$C_n\ H_m + xO_2 + 3.76\ xN_2 \rightarrow a_1\ CO_2 + a_2\ H_2O + a_3\ N_2 + a_5\ CO$ (12)

Where a_5 is the number of moles of CO.

The mass balance of carbon, hydrogen, nitrogen and oxygen gives:

For Carbon $a_1 + a_5 = n$ (13)

$a_1 = n - a_5$

For Hydrogen $a_2 = m / 2$ (14)

For Nitrogen $a_3 = 3.76\ x$ (15)

For Oxygen

$a_5 + a_2 + 2\ a_1 = 2x$ (16)

$a_5 = 2x + m / 2 - 2a_1$ (17)

$a_5 = 2x + m / 2 - 2n + 2\ a_5$

$a_5 = 2n + 2x + m / 2$ (18)

and

$a_1 = n - 2n + 2\ x - m / 2$

$a_1 = 2x - m / 2 - n$ (19)

the total number of moles of fuel vapour, residual gas and air in the cylinder at trapped condition can be calculated from the equation:

$N_T = \frac{PV}{RT}$ (20)

P = cylinder pressure at trapped condition (kPa)

T = cylinder temperature at trapped condition (K)

V = cylinder volume (m^3)

R = universal gas constant (Kg / mole . K)

The composition at trapped conditions is calculated as follows:

$NC_nH_m = K_1$ (21)

$NCO_2 = a_1K$ (22)

$NH_2O = a_2K_2$ (23)

$NH_2 = 3.76\ x + a_3K_2$ (24)

$NO_2 = x + a_4K_2$ (25)

$NCO = a_5K_2$ (26)

Where K_1 and K_2 are scale factors reducing the mole numbers to the proper size to fit in the engines.

$K_1 = \frac{NT - Nr}{Na}$ (27)

$K_2 = \frac{Nr}{Npr}$ (28)

Where,

N_a : number of moles of air plus fuel (vapor / gas) in a mixture containing 1 mole of fuel

N_{pr} : number of moles of products formed from the combustion of N_a

N_T : number of moles of fuel (vapor / gas) and air in to engine at trapped condition

N_r : number of moles of residual exhaust from previous cycle in the engine

Heywood, showed that the typical residual fraction in spark ignition engines range from (5% - 20%).

Environmental effects of exhaust gases

Carbon dioxide is an odourless, colourless gas, which is faintly acidic and non-flammable.

Carbon dioxide is a molecule with the molecular formula CO_2. The linear molecule consists of a carbon atom that is doubly bonded to two oxygen atoms, O=C=O.

Although carbon dioxide mainly consists in the gaseous form Due to human activities, the amount of CO_2 released into the atmosphere has been rising extensively during the last 150 years. As a result, it has exceeded the amount sequestered in biomass, the oceans, and other sinks

CO_2 is one of the most important greenhouse gases which convert sunlight reaches the earth into heat and trap it near the earth's surface, so that the earth is warmed up, yet, the increase in CO2 concentration in the air will lead to serious environmental problems that the earth's climate is changing because the temperatures are rising. This unnatural addition to the greenhouse effect is known as global warming. It is suspected that global warming may cause increases in storm activity, Melting of ice caps on the poles, which will cause flooding of the inhabited continents, and other environmental problems

During the last decade, Humans have been increasing the amount of carbon dioxide in air by burning of fossil fuels. About 22% of the current atmospheric CO_2 concentrations exist due to these human activities. Carbon dioxide emissions have risen from 280 ppm in 1850 to 364 ppm in the 1990s, Increasing carbon dioxide emissions cause about 50-60% of the global warming.

Increasing CO_2 concentrations have also various bad impacts on health, the primary health dangers of carbon dioxide are:
- Asphyxiation. Caused by the release of carbon dioxide in a confined or unventilated area. This can lower the concentration of oxygen to a level that is immediately dangerous for human health.
- Kidney damage or coma. This is caused by a disturbance in chemical equilibrium of the carbonate buffer. When carbon dioxide concentrations increase or decrease, causing the equilibrium to be disturbed, a life threatening situation may occur

Carbon monoxide is a colorless, odorless gas that is formed when carbon in fuel is not burned completely. It is a component of motor vehicle exhaust, which contributes about 56 percent of all CO emissions nationwide. Other non-road engines and vehicles (such as construction equipment and boats) contribute about 22 percent of all CO emissions nationwide. Higher levels of CO generally occur in areas with heavy traffic congestion. In cities, 85 to 95 percent of all CO emissions may come from motor vehicle exhaust. Other sources of CO emissions include industrial processes (such as metals processing and chemical manufacturing), residential wood burning, and natural sources such as forest fires. Woodstoves, gas stoves, cigarette smoke, and unvented gas and kerosene space heaters are sources of CO indoors. The highest levels of CO in the outside air typically occur during the colder months of the year when inversion conditions are more frequent. The air pollution becomes trapped near the ground beneath a layer of warm air.

Carbon monoxide can cause harmful health effects by reducing oxygen delivery to the body's organs (like the heart and brain) and tissues.

-Cardiovascular Effects: The health threat from lower levels of CO is most serious for those who suffer from heart disease, like angina, clogged arteries, or congestive heart failure. For a person with heart disease, a single exposure to CO at low levels may cause chest pain and reduce that person's ability to exercise; repeated exposures may contribute to other cardiovascular effects[3].

- Central Nervous System Effects: High levels of CO can affect even healthy people. People who breathe high levels of CO can develop vision problems, reduced ability to work or learn, reduced manual dexterity, and difficulty performing complex tasks. At extremely high levels, CO is poisonous and can cause death[4].-Smog: CO contributes to the formation of smog, ground-level ozone, which can trigger serious respiratory problems.

Conclusion

1. The best combustion process occurs when the mixture is stochiometric fuel – air ratio which means a complete combustion for all the fuel entering the combustion chamber.
2. When the mixture is lean, excess air will be emitted.
3. When the mixture is rich, CO will be emitted to the atmosphere as a reaction product which has a serious bad impact on the environment.

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